TERRESTRIAL SEQUESTRATION: AN ADAPTATION AND MITIGATION STRATEGY

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ABSTRACT

Protecting, enhancing and re-introducing vegetation and soil carbon has multiple benefits. Storm-water management, erosion control, reduced urban energy demand and improved air quality can be achieved through sequestering carbon for atmospheric CO_2 reduction. The mechanisms of evapotranspiration and wind shelter ameliorate the trend toward high temperature extremes, while soil carbon enhances water infiltration to the subsurface. In this context, the forestry community could contribute knowledge and experience gained in managing urban and native forests to help cope with today's climate variability and extreme weather events, which serve as a learning basis for adapting to climate change. This paper will focus on the primary and secondary benefits of terrestrial carbon sequestration in metropolitan areas of the U.S.

BACKGROUND

Of the many questions posed by policy makers to address the possible outcomes of global warming, two important ones are: What are the vulnerabilities of human systems to global environmental change; and how can they be reduced? Possible outcomes of global climate change include a continuing trend of higher summer temperatures, earlier snow-melt, and more extreme weather events. Human systems are organized around urban centers, which experience a distinct phenomena of localized climate change, called the urban heat island effect (UHI). Urban areas experience a heat island effect because of multiple forces, most important are the heat-capturing structure of buildings and asphalt and the diminished volume of vegetation. Hotter urban areas force residents to consume more energy during the summer, which lead to higher CO_2 emissions, potentially causing an enhanced greenhouse effect. The urban heat island effect and global warming are separate issues related by their outcomes.

Although the impact of climate change is uncertain, current actions taken to adapt to climate variability and extreme weather events serve as a learning basis for long-term climate change. A predicted higher rate of severe weather events may increasingly compromise flood control systems, and the urban heat island effect has shown temperatures in urban areas are rising 1.5 times faster than the global average. The UHI effect has also been linked to changes in regional weather events such as isolated convective thunderstorms.

Policies introduced to aid in the stabilization of greenhouse gases range from those that recognize CO_2 as a pollutant under the federal Clean Air Act – Including it as part of legislation controlling multipollutants from power plants - to those that provide local incentives for enhancing terrestrial ecosystem carbon storage. The cost to industry of compliance with mandatory legislation, although not incurred immediately in most proposals, is high. Enhancing terrestrial carbon sequestration in strategic locations in the near term, on the other hand, has net financial benefits and serves the dual role of sequestering carbon and enhancing ecosystem services.

Forests provide oxygen, remove pollutants from the air, and add carbon to the soil. Rain that infiltrates soil replenishes groundwater reservoirs, and water evaporation from vegetation and soil keeps air cool in summer. The long–term conversion of grassland and forestland to cropland, grazing lands, and eventually urban areas has resulted in historic losses of soil carbon. Harvesting plants precludes their being deposited in the soil, and tillage breaks down the organic carbon already in the soil, releasing it to the atmosphere. In the transition of a native ecosystem from forest or wetland to human use area, vegetation and soil porosity decrease dramatically. Above and below ground carbon stores decrease. A concurrent fall-off of valuable services places more pressure on urban storm-water drainage and climate control systems. This paper focuses on the benefits of increasing urban terrestrial carbon sequestration and enabling policies, legal frameworks, environmental and development planning.

TERRESTRIAL CARBON SEQUESTRATION

Climate adaptation is any passive, reactive, or anticipatory action taken to adjust to changing climatic conditions. Terrestrial sequestration actions taken to mitigate adverse effects of urban warming are both reactive and anticipatory, and provide significant ancillary benefits. Currently terrestrial carbon uptake offsets roughly one third of global anthropogenic CO_2 emissions. The uptake from domestic terrestrial ecosystems is expected to decrease 13% over the next 20 years as northeastern forests mature, but there are significant opportunities for low-cost terrestrial sequestration projects in certain regions and in forestalling net carbon loss from ecosystems. Small potential reservoir size, difficulties in monitoring and verification, and uncertainty about the length carbon can be effectively stored in these systems are limiting features, but four major pathways for terrestrial carbon sequestration could allow for dual mitigative and adaptive roles. These are:

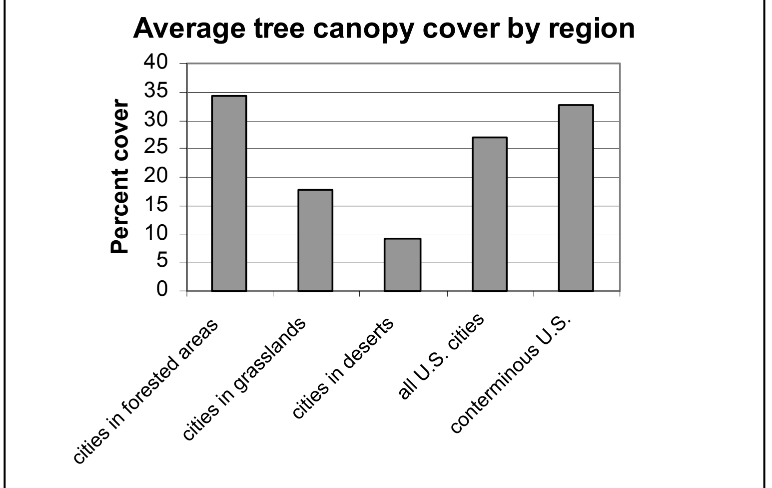
- Protect and manage existing native ecosystems
- Improve land reclamation processes and reforestation
- Extend the use of "carbon friendly" agricultural practices
- Increase forest and other vegetative cover in metropolitan and urban areas

Forest preservation maintains biodiversity; reclamation of degraded lands can improve the structure and function of soil and water infiltration; the use of "carbon friendly" technologies, such as no-till, minimum till, using cover crops and mulching, improves the permeability and structure of soils; and increasing urban forests provides flood and erosion control, and reduces peak energy demand and air pollution.

URBAN TERRESTRIAL SEQUESTRATION

The knowledge of the forestry community can help form an adaptation strategy that sequesters carbon, is participatory and culturally acceptable to the community, and integrates adaptation measures into natural hazard reduction and disaster prevention programs. Current U.S. Forest Service research includes studies on urban tree carbon storage and annual sequestration, reductions in CO_2 emissions from power plants resulting from more efficient building energy use, quantification of CO2 emissions from vegetation maintenance, and the net CO_2 effects from urban forest management. Other research by forest professionals and institutions includes management of rural and urban forests to maximize carbon sequestration.

The U.S. Departments of Agriculture and Energy have ongoing research and development projects in each of these areas, with the DOE Carbon Sequestration Program work focused on terrestrial systems that integrate energy production, conversion, and use with biotic sequestration activities. The EPA initiated the Heat Island Reduction Initiative (HIRI), which promotes heat island reduction strategies. Planting shade trees and increasing urban vegetative cover are two actions that the EPA has identified in its work with stakeholders to mitigate the heat island effect. Urban Forestry councils, required by Congress to receive Urban Forestry funding under the 1990 omnibus Farm Bill, now exist in every state. The U.S. has a foundation for further action already in place.



Source: USDA Forest Service 2000

Metropolitan areas cover 24.5 percent of the conterminous United States, and between 1950 and 1990, metropolitan areas nearly tripled in size. Urban areas cover 3.5 percent of the U.S. and offer a greater amount of data, so we will focus on the urban subset of an inclusively metropolitan problem. The density of trees in almost all U.S. urban counties has been decreasing, some, such as San Antonio TX, and Washington DC, by as much as 20 percent over twenty years. Nowak and Crane estimate that urban trees in the contiguous U.S. currently store 700 million tons of carbon, equal to half the total CO2 emissions of the U.S., and have a gross carbon sequestration rate of 22.8 million tons per year carbon. The national average urban forest C storage density is 25.1 tons C per ha, compared with an average native forest stand storage density of 53.5 tons per ha. Opportunities for enhanced urban terrestrial uptake include increasing tree cover by at least ten percent on 500 million acres of metropolitan and urban land. Southeaster states' urban areas have the highest sequestration rates, averaging roughly one million tons per year per state.

The urban forest resource differs in extent across the United States. The Northeast is the most urbanized portion of the Nation, and also tends to have a higher proportion of tree cover in urban areas. New Jersey has 22.3 percent tree cover, Massachusetts 14.4 percent, and Connecticut 14.0 percent. States with the largest urban tree populations are generally in the South and Northeast and include Georgia (232.9 million urban trees), Alabama (205.8 million), and Ohio (191.1 million). Cities that developed in forested areas average 34.4 percent tree cover; cities in grasslands, 17.8 percent; and cities in deserts, 9.3 percent. The non-profit organization American Forests, which has developed software to analyze specific cities based on satellite imagery, recommends a 25 percent tree cover for urban areas in arid regions of the U.S. Heavy tree cover is defined as an area with greater than a 50 percent canopy. Table 1 shows the breakdown of aggregate data gathered for conterminous U.S. urban forests.

Table 1. U.S. urban land area, carbon storage and sequestration

% urban land	Land area (Sq km)	stored tC	% tree cover	Sequestered tC/y	t/ha/y	000s of trees
3.5	281,000	704,397,000	27.1	22,845,000	0.8	3,820,491

Note: carbon sequestered does not take into account carbon avoided through energy reduction benefits.
Source: *Connecting People with Ecosystems: an assessment of our Nation's urban forests*, USDA Forest Service 2000

Storm-water control

Soil carbon promotes the formation of aggregates, which enhance porosity and water infiltration. Carbon contained in soil can be organic or inorganic, though inorganic carbon, formed through chemical processes such as weathering, represents a small fraction of the total. Plants convert CO_2 into leaves and tissue-organic carbon-through photosynthesis, and the carbon is eventually deposited in soil through roots and in plant residue. Land development reduces the quantity of water that may infiltrate to the subsurface two ways: through impervious surface area expansion, and loss of vegetation and soil organic matter. Both outcomes contribute to a loss of soil aggregates, which enhance soil porosity.

In San Antonio TX, a survey report concludes that tree loss in the area between 1985 and 2001 increased the amount of storm-water flow during a peak storm event by an estimated 73 million cubic feet. At $2 per cubic foot to build a storm-water system, the vegetation-in-place is estimated to be equivalent to saving $146 million. In another study also by American Forests, a medium-size, 3.86-ac. residential site with 8% canopy cover provided a 3% runoff reduction. If the site's tree canopy were increased to 35%, runoff was reduced by 12.8%. Horticulturists estimate that trees' minimum weekly water needs equal a 5-gallon base amount plus 5 gallons per caliper inch (diameter measurement). A mature bald cypress can absorb 880 gallons per day, depending on the soil type and saturation.

Some developments use bioswales, which are shallow green ditches seeded with indigenous plants that will improve storm-water management, like a constructed marshland or wetland, which also generate additional ecosystem services. In light of the multiple services that vegetation provides, foresters are increasingly teaming up with engineers and city planners to solve storm-water problems.

Reduced Thermal Emissions

Tree canopy is known to have a strong negative relationship with net urban thermal emissions. In rural locations a significant portion of incoming solar energy evaporates water from vegetation and soil. This is called the latent heat of vaporization. In areas without open soil and vegetation, solar energy is simply absorbed as heat. As a result, air temperature rises more rapidly in cities. During the night, the stored heat energy in roads and other structures is slowly released into the air, which keeps cities as much as ten degrees warmer than rural areas at night as well as during the day. Tall buildings also block infrared radiation from escaping and further slow the cooling process. Waste heat from air-conditioners can add as much as two degrees to outdoor urban temperatures, and tends, along with the heat produced from cars, trucks and factories, to get trapped close to the ground by high-pressure weather systems. Local topography and local wind flows, the city's mass, and amount of evapotranspiration all affect the reduction of wind speed and the alteration of the water balance.

Maximum mid-day air temperature reductions from trees are in the range of 0.04°C to 0.2° per percent canopy cover increase. Nationally, urban tree cover averages 27.1%, but the mean annual tree budget for cities across the U.S. has fallen 40% since 1986, so cities have lost a natural brake on 0.5° to 4° degrees C temperature increase. Reductions in air temperature are correlated with improved air quality because the emissions of many pollutants and/or ozone-forming chemicals are temperature dependent. Decreased air temperature can also reduce ozone formation. Large healthy trees greater than 77 cm in diameter remove approximately 70 times more air pollution annually (1.4 kg/yr) than small healthy trees less than 8 cm in diameter (0.02 kg/yr).

About 5-10% of the current urban electricity demand is consumed for the purpose of cooling buildings to compensate for the increased UHI temperature. In San Antonio residents use their air conditioners at an approximate cost of $555 dollars per home annually. Residential shade trees were shown by American Forests to save each home an average of $76 a year. Assuming that 67.8 percent of the area's residences have air conditioners (U.S. Census Bureau), the estimated annual residential savings total $17.7 million. According to a study from LBNL, mitigation of urban heat islands offers potential to reduce national energy use for air conditioning by 20% while improving urban air quality.

Another possible step is to plant greenery on building rooftops, where plants give off moisture and provide insulation, lower temperatures inside and outside buildings. An 8-sq.-meter patch of lawn on a rooftop is estimated to produce the same cooling effect as operating an air conditioner for one day. In spring 2001, the Tokyo government enacted an ordinance that requires builders to plant greenery on the rooftops of new or reconstructed buildings of a certain size. In the April-June period, 3.5 hectares (8.65 acres) worth of rooftop gardens were planted in the metropolitan area, up 40% from a year earlier, to bring the total of such greenery to more than 19 hectares at the end of June, Tokyo authorities said. Takenaka Corp. has advertised in Tokyo and Osaka its light-soil technology for use in rooftop gardens. It planted 5,000 sq. meters of greenery on the rooftops of the Kansai-kan of the National Diet Library in Kyoto, one of the largest such projects in Japan. Taisei Corp. will start selling a product that offers easy planting of ivy and other greenery on building walls and fences. The price starts at almost $700 per square meter, including installation. In Singapore, a survey by the National Park system showed that rooftop gardens, also called skyrise greening, can effectively reduce ambient air temperatures by as much as 4°C, also insulating the building.

For individual homes in neighborhoods with low building density or in rural areas, trees may reduce annual heating and cooling costs by up to 25 percent compared to the same areas with no trees. Trees can decrease energy use by reducing wind speed in winter, by shading and lowering air temperatures in summer, and sometimes by increasing air temperatures in winter. There are, however, a few potential negative effects of tree planting, and plantings need to be planned carefully. Trees can increase energy use by shading buildings in winter, and perhaps by adding humidity in summer. Tree effects on wind in summer may or may not be beneficial, depending upon air temperature. When air temperature is very high, lower wind speeds save energy by reducing flow of hot air into and around a house. With cooler air temperatures and strong sun, lower wind speeds may increase energy use by reducing building surface cooling and the possibility of natural ventilation through open windows. Optimizing building and tree configurations for maximum energy conservation requires balancing the positive and negative tree influences over an average year. Recent accomplishments by the U.S. Forest Service include computer simulations contrasting the effects of windbreaks around a modeled house in seven different climates. Estimates of annual energy savings for heating and cooling ranged from 0 to about 20 percent, depending upon climate and windbreak configuration.

LEGAL FRAMEWORKS

The Clean Water Act (CWA) and Federal wetlands regulation indirectly affect planning through permitting, but urban land use (zoning) is not an area of responsibility the Constitution grants to the Federal government. Most states leave zoning decisions to local Counties and municipality communities, but there are some exceptions where states take a stronger role to protect the environment. Vermont has a law that requires new developments over a certain size to meet environmental criteria, as decided by the state. Portland, OR has a regional government, comprised of several adjoining cities, which aggressively-plans development within an "urban growth boundary." Ashland, OR uses a performance-based system with a “bonus point” scoring system for increased densities, including for conservation construction. Santa Barbara, CA has instated a conservation subdivision design where 40% of the subdivision is open space. Planning policies and regulations do not specifically speak to carbon sequestration or mitigating climate change, but several articles in the city planning literature show a growing awareness of interconnected benefits of a green infrastructure.

CONCLUSION

Urban forests may have a greater impact per area of tree canopy cover than non-urban forests because of secondary effects of reduced energy use and consequent reductions in carbon emissions from power plants, faster growth rates, and increased proportion of large trees. In development planning, architects, city planners and biologists are recognizing the benefits of sustainable design. Enhancing urban forest sequestration offers immediate environmental and consumer benefits.

Integrating the forestry, EPA, carbon sequestration research and urban planning communities can improve management plans and national policies that can significantly improve environmental quality and human health.

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